Development of Film Actuator Controlled by Hydrogen Pressure for Fuel Cell

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ABSTRACT: A new high power bi-material actuator, driven by the large volume expansion of hydrogen storage $LaNi_5$ alloy film on a polyimide substrate, was prepared using a flash evaporation method. The reversible shape change was operated by hydrogen absorption and desorption. In order to apply this material to a practical actuator, the load dependence of strain yielded by shape change is an excellent potential. In this study, the strain was measured under different loading stresses. The results showed that large shape changes were induced by hydrogen operation under large loading stress.

INTRODUCTION

The hydrogen storage alloy is potentially attractive material to develop high power bimetal actuators because of a large volume expansion over 20 % by hydrogen absorption (Willems, et al., 1984, Sakai, et al., 1990). If a new actuator using hydrogen storage alloy was developed, the strong power could be triggered by change in hydrogen absolute pressure around the sample and could be operated with and without temperature change. Hydrogen storage La-Ni alloy film prepared by flash evaporation showed the reversible shape change, which was operated by hydrogen absorption and desorptions (Yabe, et al. 2003). This bi-material actuator was driven by the large volume expansion of hydrogen storage $LaNi_5$ alloy film (Honjo, et al. 2003). In previous work, $LaNi_5$ alloy has been pulverized by hydrogen absorption and desorption cycles (Uchida, et al., 1984, Kuji, et al., 2002). A thin film of the alloy showed high resistance to pulverization and long fatigue lifetime. The long lifetime is expected for any new actuator driven by a $LaNi_5$ alloy film. In order to apply this material to a practical actuator, the load dependence of strain yielded by shape change is a serious problem. Thus, the purpose of the present work is mainly to evaluate the load dependent shape change of the new high power actuator for fuel cell. Fuel cells have several very desirable features: they operate relatively cleanly and silently, can use a variety of fuels, and are generally unaffected by storms and other calamities (Lloyd, 1999.). Figure 1 shows the pressure control system of the fuel cell of the actuator material using the hydrogen storage alloy. Actuator of no-pulverized hydrogen storage alloy film will be expected for pressure controller of fuel cell.

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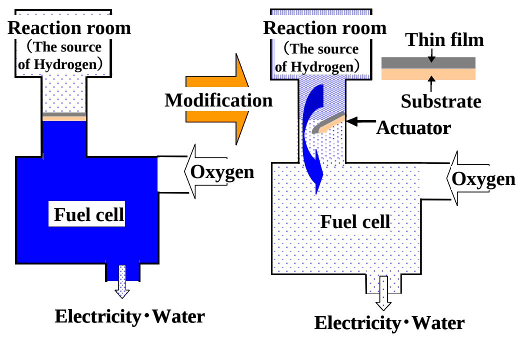

Figure 1. *Schematic diagram of the actuator material in pressure control system of fuel cell. (Ref. The Institute of Electrical Engineers of Japan)*

EXPERIMENTAL PROCEDURE

$LaNi_5$ hydrogen storage alloys were prepared

Report Documentation Page			*Form Approved* *OMB No. 0704-0188*
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1. REPORT DATE **00 JUN 2003**	2. REPORT TYPE **N/A**		3. DATES COVERED **-**
4. TITLE AND SUBTITLE **Development of Film Actuator Controlled by Hydrogen Pressure for Fuel Cell**			5a. CONTRACT NUMBER
			5b. GRANT NUMBER
			5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)			5d. PROJECT NUMBER
			5e. TASK NUMBER
			5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Department of Materials Science, TOKAI University, 1117 Kitakaname, Hiratsuka, Kanagawa, 259-1292 JAPAN**			8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSOR/MONITOR'S ACRONYM(S)
			11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release, distribution unlimited**			
13. SUPPLEMENTARY NOTES **See also ADM001697, ARO-44924.1-EG-CF, International Conference on Intelligent Materials (5th)(Smart Systems & Nanotechnology)., The original document contains color images.**			
14. ABSTRACT			
15. SUBJECT TERMS			

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**3**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

by arc melting (ACM-DS01 DIAVAC Ltd.) and subsequent annealing for homogenization. The block sample was pulverized by several hydrogen cycles of adsorption and desorption using ultra high purity H_2 gas (7N), the resulting powder was classified to obtain a mean grain size between 25 and 45 µm in diameter. To obtain hydrogen storage thin films that showed high resistance to pulverization and fatigue, thin films were prepared by the flash evaporation process using the pulverized $LaNi_5$ powders on polyimide substrate (Kapton (R) 500V, DU PONT-TORAY Co. Ltd.). The substrate temperature was varied from 297 K to 386 K. The base pressure was less than 1.0×10^{-3} Pa. The dimensions of the polyimide substrate were 18 mm in width, 18 mm in length, and 0.125 mm in thickness. The chemical composition of the hydrogen storage alloy film deposited was analyzed by energy dispersive X-ray spectroscopy (EDS: JSM-6301F, JEOL Ltd.) as $LaNi_5$. The thickness of the $LaNi_5$ film was sub-micron mater to prevent pulverization (Yabe, et al. 2003, Honjo, et al. 2003). The deposited hydrogen storage $LaNi_5$ alloy films were then transported to a reaction bed made of silica glass (see Figure 2). After evacuation for hydrogen desorption, the material shape change under different loads was monitored by a video recorder (Kim, et al., 2001, Yabe, et al., 2003, Honjo, et al., 2003).

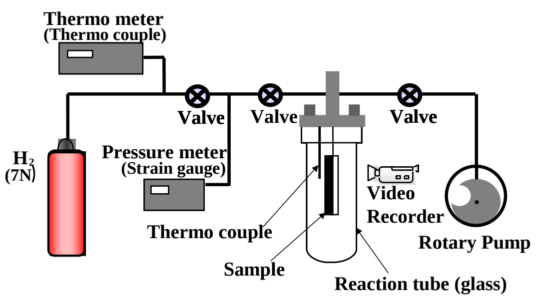

Figure 2. *Schematic diagram of shape change observation system.*

The strain measurement of the actuator was defined as shown in Figure 3 and equation (1) to (5). The movable strain (ε) was calculated by equation (1) & (2) using the radius of curvature (ρ) at the mid point and a half thickness (η) of the bending sample. We set the ρ value equal to the distance between the interface and the exterior of the sample, while η was defined as the substrate thickness.

$$\varepsilon = \eta / \rho \qquad . (1)$$

The strain difference ($\Delta\varepsilon$) yielded by shape change of the hydrogen storage alloy bi-polymer before and after hydrogen gas absorption was defined as equation (2).

$$\Delta\varepsilon = \varepsilon - \varepsilon_0 \qquad (2)$$

Here, ε_0 is initial strain before the first hydrogen absorption in glassy reaction tube.

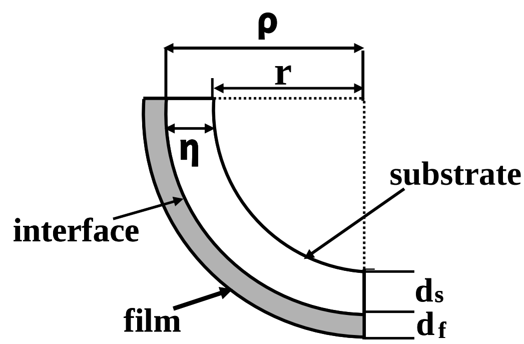

Figure 3. *Schematic diagram of the method for strain (ε).*

RESULTS AND DISCUSSIONS

One serious obstacle to applying such a material to a practical actuator is its load dependence strain yielded by the shape change. To evaluate the load dependence, the strain was measured at different loading stresses. Figure 4 shows the relationship between the applied hydrogen operation time (s) and the strain yielded by shape change $\Delta\varepsilon$ (ppm) of hydrogen storage alloy film at different loads. Large strain was induced long hydrogen operation time. The large strain over 150 ppm was observed at above 600 s of operation time of unloaded sample. When the load was large, the pressure-strain curve was small. Hence, the load dependence was observed at hydrogen storage $LaNi_5$ alloy film.

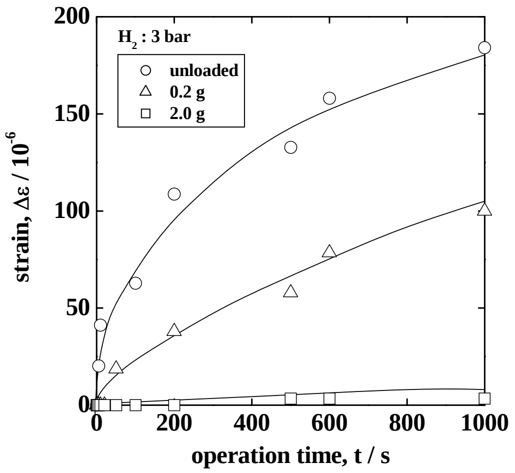

***Figure 4**. Relationship between applied hydrogen operation time (s) at hydrogen pressure of 3 bar and strain yielded by shape change $\Delta\varepsilon$ (ppm) of hydrogen storage $LaNi_5$ alloy film at different loads.*

Figure 5 shows the relationship between the load (g) and the maximum strain yielded by shape changes $\Delta\varepsilon$ (ppm) of the hydrogen storage alloy film. The load decreased the maximum strain yielded by the shape change. The results indicate that the high hydrogen pressure induced the large strain and could operate under a large film loading condition.

CONCLUSION

A new high power bi-material actuator, driven by the large volume expansion of hydrogen storage $LaNi_5$ alloy film on a polyimide substrate, was prepared using a flash evaporation method. A large strain change was induced in the material, which was operated by the hydrogen pressure change. These measurements suggest that a new hydrogen storage alloy-based actuator could be developed that would be expected for new type actuator material for fuel cell.

ACKNOWLEDGEMENT

The authors would like to thank Dr. Yoshihito Matsumura, Mr. Shingo Tsubuteishi and Naoki Okada in Tokai University, and DU PONT-TORAY Co. Ltd.. In addition, parts of this study were carried out by grant-in-aids for Scientific Research (No. 06659) from the Japan Society for the Promotion of Science.

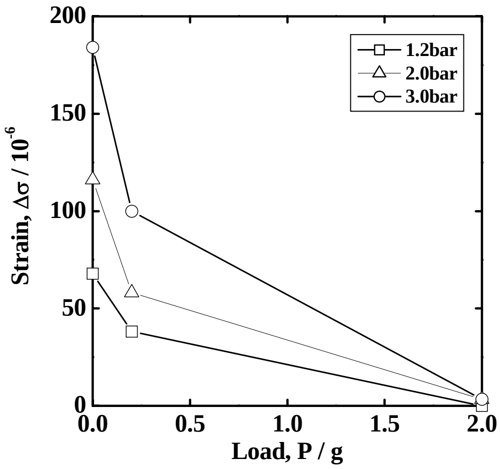

***Figure 5.** Relationship between the load (g) and the maximum strain yielded by shape changes $\Delta\varepsilon$ (ppm) of hydrogen storage alloy film at different hydrogen pressure (bar).*

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